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**DEVELOPMENT OF NEW EQUIPMENT FOR
MAKING CURVED WOOD PRODUCTS**

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MUNICIPAL AFFAIRS
Housing Division





FOREWORD

DEVELOPMENT OF NEW EQUIPMENT FOR MAKING CURVED WOOD PRODUCTS

January 1993

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The views and conclusions expressed and the
recommendations made in this report are entirely
those of the authors and should not be construed
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FOREWORD

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The Program offers assistance to builders, developers, consulting firms, professionals, industry groups, building products manufacturers, municipal governments, educational institutions, non-profit groups and individuals. At this time, priority areas for investigation include building design, construction technology, energy conservation, site and subdivision design, site servicing technology, residential building product development or improvement and information technology.

As the type of project and level of resources vary from applicant to applicant, the resulting documents are also varied. Comments and suggestions on this report are welcome. Please send comments or requests for further information to:

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EXECUTIVE SUMMARY

BACKGROUND

Demand is increasing for circular stairways, archways, and oval and curved-top windows in residential construction. Builders, window manufacturers, retrofitters, architects, and building supply companies surveyed for this project confirm that homeowners are showing a growing preference for curved wood elements to improve the aesthetic appeal of their homes. Needless to say, the industry is very interested in meeting this demand.

Lamination, the best method for manufacturing wood arches, has been limited. Specialized arch-making equipment is not easily available in Canada, but, more important, existing laminating, arch-making, milling, and profiling machines have many limitations.

OBJECTIVE OF THE PROJECT

The main purpose of this project was to develop and evaluate cost-effective new machines for manufacturing high quality laminated, curvilinear (two-dimensional) and helical (three-dimensional) arches for use in residential construction.

SCOPE AND FOCUS

This project comprised the development, building, and testing of four machines for manufacturing arches to an installation-ready stage. The focus for the development of these machines was to overcome the limitations of existing laminating, arch-making, milling, and profiling equipment.

ASSESSMENT OF LIMITATIONS OF EXISTING EQUIPMENT

Assessment of the available arch-making machinery suggests most have high capital costs, which could be prohibitive for small manufacturing firms. The major drawback of existing machinery, however, is it is expensive to operate. It is labour-intensive and time-consuming.

Existing machinery has three main operating shortcomings:

- (1) high operating costs because it requires extensive labour and facilities; often, existing equipment takes more time to set up than to form or mill the arch;
- (2) limited versatility, being unable to manufacture arches of varying sizes and shapes; existing equipment is able to perform either job-lot manufacturing or smaller custom orders, but seldom both; and
- (3) problems with consistency and quality of the arch shape and quality of the lamination itself; mechanical limitations and human error hinder the ability to consistently manufacture structurally sound and aesthetically appealing marketable arches to varying architectural specifications.

These shortcomings inhibit manufacturers from achieving levels of versatility and client-responsiveness necessary in today's marketplace.

DEVELOPMENT AND TESTING OF PROJECT MACHINERY

The project equipment was designed, developed, and tested to achieve the following goals in the manufacture of laminated arches:

- (1) increased cost-effectiveness;
- (2) increased versatility; and
- (3) improved quality and consistency.

Four machines used in arch manufacturing were designed, built, and tested:

- (1) The **Universal Laminating Device (ULD)**--a machine that simultaneously forms and laminates curved wood members into curvilinear (two-dimensional) arches and helical (three-dimensional) arches;

- (2) The **Curvilinear Multi-Rip Saw (CMRS)**--a machine for slicing or ripping large laminated arched wood members into rough stock (milling);
- (3) The **Vertical Arch Profiling Device (VAPD)**--a lightweight upright machine to vertically profile rough stock; and
- (4) The **Horizontal Arch Profiling Device (HAPD)**--a lightweight upright machine for horizontally profiling rough stock.

CONCLUSIONS

The following conclusions can be drawn from this project:

- (1) The machines currently available to arch manufacturers have many limitations. They are not conducive to cost-effectiveness, versatility, or quality manufacturing.
- (2) The machines developed and tested during this project--the Universal Laminating Device (ULD), the Curvilinear Multi-Rip Saw (CMRS), the Vertical Arch Profiling Device (VAPD), and the Horizontal Arch Profiling Device (HAPD)--all overcome the limitations found in the currently available machinery.
- (3) The machines developed and tested in this project achieved the goals of:
 - (a) increased cost-effectiveness by minimizing needed manufacturing space and reducing labour costs (because of decreased set-up times), thereby increasing productivity;
 - (b) increased versatility and improved customer-service and market-responsiveness through reduced batch size, and even one-of-a-kind production; and
 - (c) improved quality through reduced manual work and therefore less human error.

- (4) The estimated capital costs of the ULD, CMRS, VAPD, and HAPD are significantly less than existing arch-making machinery.
- (5) The machines and their manufacturing process can effectively meet the needs of Alberta's new and retrofit construction industry, where curved wood elements and finishings are increasingly being demanded by homeowners.

1.0 INTRODUCTION

1.1 BACKGROUND

In residential construction, recent changes in consumer tastes have increased the demand for circular stairways, archways, and circular, oval, and curved-top windows. Curved elements are also being used increasingly in picture frames, mirrors, and furnishings. To date, this demand has been met largely by using casings and frames made up of small, curved segments of wood, arranged in an arch-shape.

Manufacturing curved wood elements by using curved wood segments, however, has serious drawbacks in structural soundness and aesthetic appeal. A much superior method for curved wood elements is lamination of thin wood strips into complex shapes. Not only does lamination allow for bending and curving into a wider variety of shapes, laminated members have superior strength and retain the consistency of the wood grain, contributing greatly to aesthetic appeal.

Unfortunately, the use of lamination in the manufacture of curved wood elements has been limited because it is currently expensive, labour-intensive and time-consuming. Usually, lamination of this sort requires large shop spaces to be devoted to the necessary machinery, moulds, and jigs required for construction of the various curved configurations. In particular, existing machinery and systems for curved element manufacture are expensive and have some significant limitations.

1.2 OVERVIEW OF THE ARCH-MANUFACTURING PROCESS

Lamination, the gluing of thin strips of wood with the grain running the same direction, is a very old method of bending wood into desired shapes. It is also the best way. Lamination is not only strong and sound, but it also retains the appeal of the wood grain. Thus, lamination is the best method for the manufacture of curved wood elements.

The process of creating laminated curved elements begins with cutting the rough lumber into strips of the required size. The surfaces of those strips are then planed to facilitate gluing, and the strips are cut to the required lengths for the particular arch being crafted. These preparation activities can take up to 50 minutes, depending on the size of the curved element to be laminated.

Once these initial material preparation activities are completed, the process of laminating the arches begins. That process has four distinct phases or steps:

- i) laminating arch frames,
- ii) ripping or slicing sections of rough arch stock,
- iii) vertical profiling of bevels and contours as required by architectural specifications, and
- iv) horizontal profiling of bevels and contours as required by architectural specifications.

1.3 PROJECT OBJECTIVE

The objective of this project was to develop and evaluate cost-effective new machinery and processes for manufacturing high quality laminated, curvilinear and helical curved-wood elements for use in residential construction. The objective for the development of these machines was to overcome the limitations of existing laminating, arch-making, milling, and profiling equipment.

1.4 SCOPE AND FOCUS

The four steps in the process of manufacturing arches to an installation-ready stage have determined the focus of this project. Specifically, the work developed, built, and evaluated the following machines:

1. a machine that can simultaneously form and laminate curved wood members into curvilinear (two-dimensional) arches and helical (three-dimensional) arches;

2. a machine that can slice or rip large laminated arched wood members into rough stock (milling);
3. a machine that can vertically profile the rough stock to marketable specifications; and
4. a machine that can horizontally profile the rough stock to marketable specifications.

1.5 RESEARCH METHODS

1.5.1 Literature Search

A trade literature search for information on arch laminating and profiling equipment was conducted.

1.5.2 Inquiries to Canadian Machinery Distributors

In conjunction with the literature search, all the woodworking machinery distributors listed in Toronto, Mississauga, Calgary, Edmonton, and Vancouver were contacted for information on their currently available equipment. That information is the basis of the assessment of laminating and profiling equipment summarized in Section 2.

However, the specialized arch-making equipment is surprisingly limited in Canada. Therefore, an attempt was made to gain additional information from European distributors. An advertisement requesting information on arch laminating equipment was placed in a European monthly woodworking machinery magazine through House of Tools (a Calgary-based machinery distributor). To date, no replies have been received.

1.5.3 Consumer Telephone Survey

Since production of curved elements must respond to the demands of the marketplace, a telephone marketing survey assessed consumer interest in and acceptance of curved windows, archways, and circular stairways in residential construction. The results reflected the consumers' perception that curved elements improve residential construction by adding aesthetic appeal.

A summary of the results of this survey, carried out by Touchstone Communications, follows. The survey contacted window manufacturers, home builders and renovators, architects, building supply centres, and mirror and picture frame suppliers.

Window Manufacturers. All the window manufacturers surveyed felt there is a definite trend toward the use of more circlehead and elliptical windows. However, 60% of the manufacturers had to purchase their window components from outside Alberta. About 50% of them used either segmented wood components or moulded plastic rather than laminations.

Builders and Renovators. Of builders surveyed, 90% felt there was a strong demand for circlehead and elliptical windows, interior wood archway kits, and miscellaneous interior decorator trim. About 66% of the renovators felt there was a trend toward half-round windows, and all the architects believed there was a strong move toward half-round windows as well as curved archways and decorative trim.

Building Supply Centres. Between 70% and 80% of the building supply centres contacted expressed interest in being able to offer decorative garage door kits, garage door corner kits, garage door mouldings, and interior decorative archway kits.

Picture Frame Suppliers. Finally, the firms that supply elliptical, oval, or round decorative wood frames for pictures and mirrors said that they sell very few such items. Approximately 50% sell both wood and moulded plastic, while 25% sell wood only, and 25% sell plastic only.

Clearly, there is a definite trend in consumer demand for curved elements in residential construction.

1.6 ORGANIZATION OF THE REPORT

Section 2, "Assessment of Existing Wood Laminating and Profiling Equipment", of this report summarizes results of an assessment of the currently available machinery used in the

manufacture of curved wood elements. The existing machines are assessed in terms of their labour and overhead costs, their versatility, and the quality of arch they produce.

Section 3, "Engineering, Assembly, and Testing of Project Machinery", describes the four machines developed for this project, outlining the basic design principles and the sequence of operation for each machine. The Section also includes information on the testing and performance of the four machines plus the resulting modifications made to the prototypes.

Section 4, "Comparison of Project Machines to Competitors", presents a summary of comparisons of the machines developed during the project and the currently available machines described in Section 2.

Section 5, "Conclusions", presents conclusions and discusses future directions and research for the machines documented in this report.

2.0 ASSESSMENT OF EXISTING WOOD LAMINATING AND PROFILING EQUIPMENT

This section assesses the features of currently available laminating, archmaking, milling, and profiling machinery. Information gained from the literature search (Section 1.5.1) used in conjunction with the experience of the inventor of the new equipment is the basis of the assessment that follows.

Seven commercial machines, representing present industry standards and commonly used by industry, were examined. Making up this total were four curvilinear laminating/arch-making machines, two machines for arch ripping and profiling, and one helical arch-making machine. It must be stressed that this was not a rigorous scientifically controlled examination; its purpose was to study the operational aspects and features of the machines to determine where, in the inventor's opinion, improvements could be made. The results were applied to the design of the Universal Laminating Device and ancillary machines, discussed in detail in Section 3.

2.1 OVERVIEW OF ANALYSIS ISSUES

Although capital costs are important, the main focus of this assessment is on how the machines operate. The key criteria for analyzing the effectiveness of the existing machines are as follows:

1. **operational cost factors**, which are a function of time, labour and overhead;
2. **versatility**, which is the ability to manufacture arches of varying sizes and configurations with minimal set-up times; and
3. **consistent quality**, which is related to the ability to consistently manufacture marketable curved wood components to varying architectural specifications, while at the same time being responsive to clients' individual needs.

2.2 LAMINATING/ARCH-MAKING MACHINES

The capital costs of the machines examined range from \$10,000 to \$120,000 (U.S., 1991).

2.2.1 Operational Cost Considerations

In addition to the 50 minutes or more required for material preparation and gluing, three of the four laminating machines examined require the manufacture of a core-mould for each shape of arch required. Each core-mould takes an average of 30 minutes to manufacture, at a cost of about \$25 (based on current, average shop-time charges). This procedure increases the time required for the laminating cycle by about five times. In fact, this core-mould set-up time takes, on average, 150% longer than the actual laminating operation itself. To change the arch configuration, the core-mould must be changed. This, in conjunction with the fact that the machines are designed for large batch production, limits their versatility. Of course, once the mould is made, it can be stocked for future use, but this requires taking up shop space and the usefulness of the mould would depend on future requests for arches of the same configurations.

The machine not requiring a core-mould has an expanded potential for arch shape. It uses an array of metal brackets that must be manually or hydraulically calibrated to assume the desired arch shape. Not only does this give greater arch shape potential, it saves labour time (compared to an alternative of using single clamps, manually applied and adjusted). However, the labour reduction achieved (approximately 30% time-savings compared to machines needing core-moulds) is minimal when viewed in terms of a capital cost that is over ten times higher.

For all the currently available machines, each individual laminating procedure takes one or two workers to perform. The time required can be as little as 3 to 4 minutes and as high as 7 to 9 minutes, with 4 to 6 minutes the average.

Furthermore, all four arch-making machines examined in this section require workers to force the laminate material into the desired arch shape, fixing it in place before the adhesive sets or closes. This procedure, which involves fitting the glued strips into the mould and adjusting the clamping system to the desired curve, takes one or two workers between 5 and 9 minutes. This step has two ramifications.

First, depending on the size and nature of the arch, fitting the laminate to the mould extends production time and may require two workers. Second, because sufficient time is needed to force the laminate into the desired shape, the adhesive used must have a "close time" (the time it takes to set) that is slow enough to let that procedure take place. A glue that has a slower close time will have a proportionately slower curing or setting time, once again extending production time and costs.

2.2.2 Versatility

The major limitation of these laminating systems is that they are geared toward large batch production. Thus, they lack the versatility and client-responsiveness of custom, one-of-a-kind, production.

Three of the machines assessed can laminate arches up to 180°, with a minimum arch width of 300 mm and a maximum arch width of 2500 mm. The maximum arch height these three machines can handle is 400 mm. The fourth machine can laminate arches up to 220°, with a minimum arch width of 300 mm and a maximum arch width of 2300 mm. The maximum arch height it can handle is 500 mm. This added capability, however, results in a significantly higher capital cost.

Two of the arch-making machines incorporate an important feature. They are capable of laminating arches with straight sections up to 1200 mm. Because of this added feature, however, the capital costs are at least twice as high (and in one case, ten times as high) as the machines that cannot produce straight sections.

To manufacture an arch of different configuration, the initial set-up of the core-mould must be changed. Changing the initial set-up of the core-mould to change the arch configuration can take anywhere from 6 to 10 minutes. For the machine using metal brackets to form the core-mould, 5 to 8 minutes are required to change them. The longest time required to change the initial set-up of the core-mould is 10 to 14 minutes on a machine where a band circumference must be changed.

2.2.3 Quality

The quality and shape of lamination are directly related to the premanufacturing of an accurate mould, which allows the possibility of human error.

The machines using core-moulds to determine arch shape are susceptible to human error since the shape of the arch depends on the accuracy of the manually formed core-mould. The machine that uses the metal bracket system creates more consistent quality of the shape. However, the set-up of the brackets still can be affected by human error.

Consistent and adequate pressure is necessary for quality lamination to take place. When only limited pressure can be applied to the laminated material, the curing time for the glue is extended. Worse, pressure will decrease proportionately as the total surface area of the arch increases, and the quality of the lamination may be affected. Overall, limited pressure capability results in increased costs and decreased quality.

For three of the machines, pressurizing of the laminated material is limited. In fact, maximum pressurizing is often limited in the currently available machines to reduce the risk of too much pressure being applied manually. Too much pressure application would result in accelerated wear on threaded components and consequent system breakdowns. In addition, pressure decreases as the total surface area of the arch increases, so not as much pressure can be applied to larger arches. That means the curing time for the glue is lengthened, sometimes to as long as 8 hours, extending the overall manufacturing time and cost involved.

With the most expensive laminating machine, higher pressure levels can be achieved, but two low-pressure areas would unavoidably exist between each pneumatic cylinder. These low-pressure areas would either require longer curing time for the glue or would weaken the arch at those points.

2.3 EXISTING RIPPING AND PROFILING MACHINES

The machines discussed in this section are used for cutting arched stock into required sizes and for profiling them with contours and bevels to architectural specifications. Profiling machines are classified as "vertical" and "horizontal", referring to the direction from which the cutting blade approaches the arch.

Two machines were examined: one performs both vertical and horizontal profiling as well as stock ripping; the other performs horizontal profiling, and has an attachment available to adapt it to vertical profiling.

Cutting and profiling machines available on today's market range in cost from about \$7,000 to \$35,000 (U.S., 1991).

2.3.1 Operational Cost Considerations

The arch cutting and arch profiling equipment discussed here takes more time to set up than to actually cut or profile the arch itself, and that constitutes the main labour cost. Depending on the total circumference of the arch and the number

of single cutting or profiling procedures to be done, the set-up time could exceed the actual cutting or profiling itself by 500% (and possibly by as much as 2500% if the equipment needs to be set up to make just one cut). For arch ripping, for example, the set-up and loading time of the laminated arch would take one or two workers approximately 3 to 5 minutes. Certain specific arch cutting requires cutting both edges. To do this with the available machinery, a second set-up would be required, thus doubling the time required. Arch cutting proceeds at approximately 100 mm to 200 mm per second, depending on the thickness of the arch and the type of wood or other material.

The set-up time for profiling machines is estimated at approximately 10 minutes.

2.3.2 Versatility

The existing arch ripping (milling) machines can handle arches up to 2600 mm wide with 1200 mm straight extensions. The minimum ripping thickness is 25 mm, and the maximum ripping thickness is 450 mm. Existing horizontal profiling equipment can machine arched segments with maximum cross-section dimensions of 80 mm x 100 mm. This equipment can also profile S-shaped arched segments with a minimum radius of 150 mm. Currently available equipment can vertically profile arched segments with a maximum of 100 mm x 120 mm and S-shaped arched segments with a minimum radius of 150 mm.

2.3.3 Quality

All existing machines produce milled and profiled arched stock to acceptable specifications. Quality of the milling and profiling can become an issue, however, because of the possibility of human error. To achieve high quality products, these machines require skilled operators because the quality control rests with the operator, not the equipment.

Furthermore, if arch segments have twisted or warped during the curing period (a fairly common occurrence), that could cause problems when ripping stock.

2.4 EXISTING MACHINERY FOR HELICAL ARCHES (CIRCULAR STAIRWAYS)

The machinery described in the preceding subsections was limited to laminating, arch-making, milling, and profiling simple, two-dimensional curvilinear arches. On the basis of the trade literature reviewed, only one machine which can laminate three-dimensional, helical, arches such as circular stair stringers, was found.

Most stair shops use an exact-size "cage" or jig to produce the desired overall shape of the stairway. In a custom stair shop, which does not rely on mass production, a temporary cage system, fabricated from 2 x 4s, could be used.

By contrast, most production stair shops build one or more permanent cage systems or jigs and sacrifice floor space with the expectations of repeating the operation. This eliminates the labour-intensive task of setting up for each individual cage.

The commercial machine examined eliminates the need for constructing temporary cages or a range of different-sized permanent ones; it can be adjusted for different stairway designs and sizes. Its capital cost is approximately \$35,000 (U.S., 1991).

2.4.1 Operational Cost Factors Considerations

The entire set-up process for constructing one stringer can be complex and time-consuming. After the wood strips are glued, two workers position the lamination bundle on the vertical machine elements. Clamps or pneumatic presses are then applied to hold the glued layers of lamination in place until the adhesive sets. This set-up and changing takes 10 to 15 minutes. This entire procedure can take about 45 minutes in the best circumstances, although a set-up time of 90 minutes for one stringer is not unusual.

Varying curves and slopes of different stairs requires adjusting the cage. Each cage system is usually equipped with horizontal track extensions on the vertical elements which

allow for some adaptations to the cage. Such adjustment procedure usually takes one worker approximately 15 minutes per cage.

2.4.2 Versatility

Laminations and wood veneers can be pressed into many shapes: curves, straight incline, or S-shaped format for stair stringers and handrails.

In an average custom stair shop, the one-of-a-kind production makes it feasible to have only one of these machines for use in a variety of design formats. However, the advantage of this versatility is offset by the necessity of repetitive assembly and dismantling.

In a production stair shop, the repetitive assembly and dismantling for each new stair cage is not cost-effective. Consequently, temporary stair cages are not practical, but because of their large production runs, production stair shops can have a variety of dedicated stair cages. This is very costly, the average 25 cages found in a typical production shop would cost about \$875,000. Further, they might require total floor space of anywhere from 5,000 to 15,000 square feet. Shop-space cost is a major drawback, and versatility is still a problem. Even if a production shop employs 20 to 30 cages, they are still limited to that number of designs.

2.4.3 Quality

The quality of the stair stringer production on a cage is directly dependent on how accurately the cage is set up and adjusted so human error may still potentially affect quality. Furthermore, because of the length of time it takes to position and clamp the laminated stringer on the cage, the adhesive used must have a longer "close time". That results in a correspondingly longer curing time, which prolongs production time and adds to the cost.

2.5 SUMMARY OF EXISTING MACHINES

In today's marketplace, the ultimate goal of any manufacturer is to increase quality, versatility, and efficiency while keeping costs down. These are the keys to market-responsive manufacturing, which in turn results in improved customer service and higher profits. The arch-making and milling machines currently available to arch manufacturers have some limitations that inhibit them from achieving these goals.

Three of the existing laminating and arch-making devices require the manufacture of a core-mould, which increases the time required for the actual laminating cycle by about five times, with resulting higher costs. The machine that does not require core-mould manufacture, however, has a very high price for most arch manufacturers. Further, the equipment can produce only a limited range of arches, and is susceptible to human error.

The arch milling machines discussed also all require time-consuming set-ups that increase labour costs. For example, depending on the total circumference of the arch and the number of cutting or profiling procedures to be done, the set-up time could be at least five times greater than the actual cutting or profiling time itself.

The assessments of existing machinery were taken into account during the design and development of the new equipment which was the focus of this project. This new equipment is described in the following section.

3.0 ENGINEERING, ASSEMBLY, AND TESTING OF PROJECT MACHINERY

3.1. INTRODUCTION

The four machines described in this section were designed to meet the requirements of the state-of-the-art manufacturing that is currently necessary, especially to meet the market demand outlined in Section 1.5.3.

In particular, the design, development, and testing of the machines addressed the following concerns:

1. To **increase cost-effectiveness** by
 - (a) minimizing set-up times, thus reducing labour costs and increasing productivity, and
 - (b) minimizing manufacturing floor space and thus reducing overhead.
2. To **increase versatility** by allowing for efficient one-of-a-kind production, thus improving customer service, enhancing market-responsiveness.
3. To **improve the quality and consistency** of the finished curved wood products by eliminating or significantly reducing the manual component of the manufacturing process to reduce the effect of human error.

3.2 UNIVERSAL LAMINATING DEVICE (ULD)

The Universal Laminating Device (ULD) is designed to form and laminate curved wood products from pre-glued layers of material. The ULD's major advance over competitive machinery is that it does this in one step, eliminating labour-intensive, time-consuming set-ups and thus reducing costs. Moreover, it is designed for greater versatility and ensures consistent quality of arch shape and lamination.

3.2.1 Description

The ULD fabricated for this project is a 6.1 m (20') by 6.1 m (20') grid built from 150 mm (6") by 150 mm (6") steel members (see Figure 3-1).

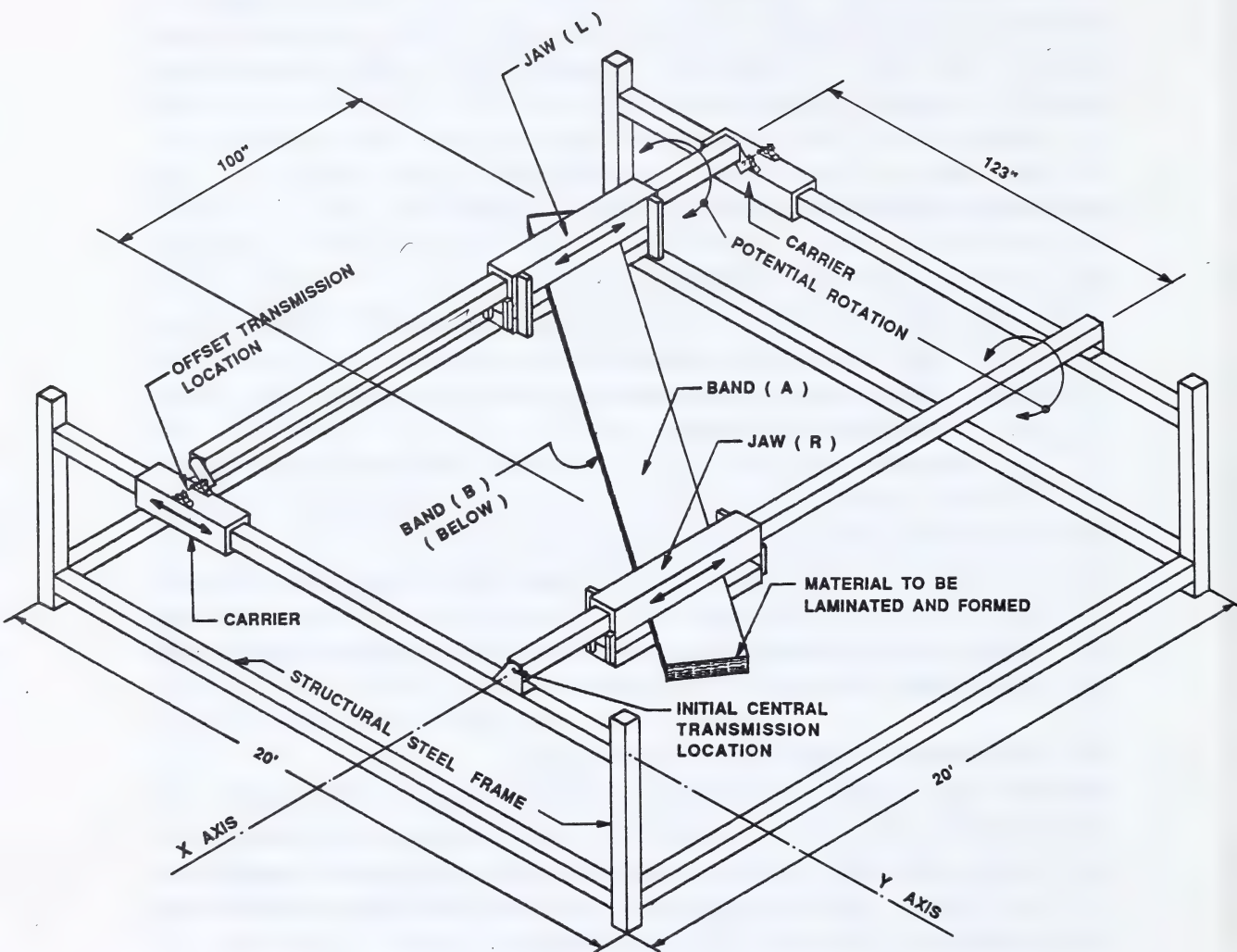


Figure 3-1: Universal Laminating Device (ULD) (Set to form a helical arch)

The ULD comprises two x-axis frames and two y-axis frames. The x-frame shown on the right in Figure 3-1 is permanently mounted perpendicular to the y-frame at both ends. The x-frame shown on the left is mounted on carriers so it can slide freely along the y-frame. Controlled by transmissions located on the x-frame, both x-frames can be rotated either simultaneously or independently. The x-frames can also be rotated in both clockwise and counter-clockwise directions.

Two jaws, each approximately 1.2 m (4') long, 225 mm (10") wide, and 660 mm (26") deep, are equipped with pneumatic clamps. Each jaw acts as a vise to hold the bands (A and B, Figure 3-1) between which the material to be formed and laminated is placed. Each jaw can slide freely along the x-axes.

The material to be laminated in the ULD is pressed between two bands (A and B, in Figure 3-1) which are held in the jaws. Bands A and B are 12 mm ($\frac{1}{2}$ ") thick wood veneer bands which will form and pressurize the lamination layers.

The bands can be repositioned within the jaws as required by differing arch specifications. The bands must have tensile strength, yet be flexible; they must also have "memory" and return to their original flat shape after laminating is completed. The composition of the material used for the bands is not important, and wood veneer, plastic, or steel can be used.

The top of the jaw that contacts the top band, Band A, has spurs that firmly grip the band when pneumatic pressure is introduced into the jaw. The surface in contact with the bottom band, Band B, is smooth. The absence of gripping spurs allows Band B to slide during the initial laminating procedure, but as is discussed below, later in the lamination procedure, sufficient pressure is applied to eliminate all band movement.

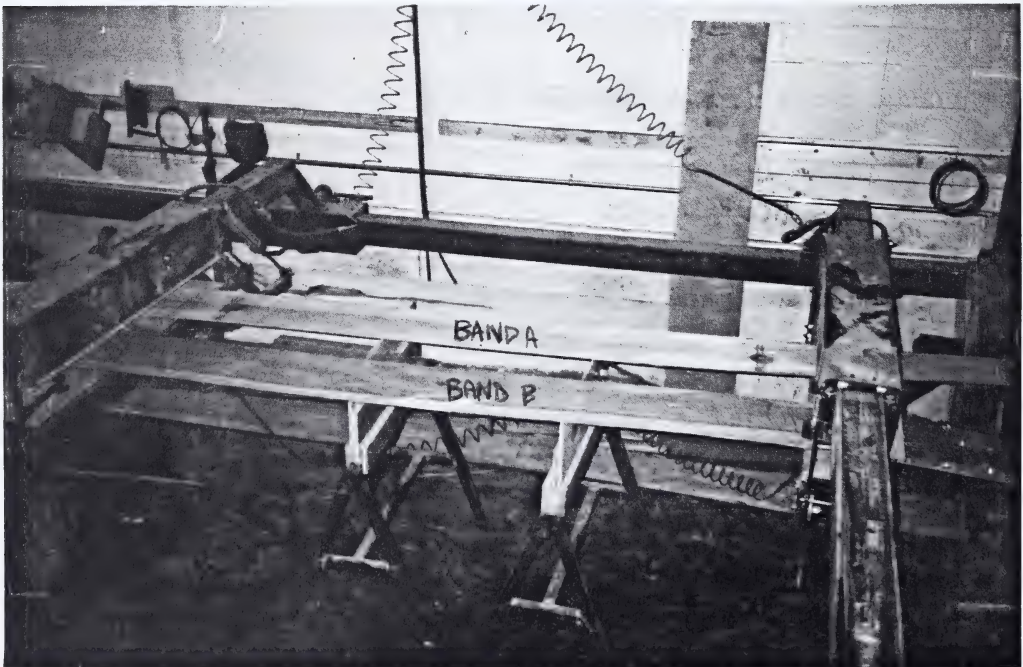
3.2.2 Capabilities

The ULD has the following capabilities:

1. it laminates curvilinear (two-dimensional) and helical (three-dimensional) arches in one step;
2. it can handle lamination of several identical arches at one time in a side-by-side configuration for high-volume applications or can laminate a single arch for one-of-a-kind applications;
3. it has a nearly unlimited range of typical residential arch sizes and shape configurations;
4. it significantly reduces set-up times;
5. it eliminates pre-mould manufacture; and
6. it reduces required floor space.

3.2.3 Basic Principles and Operational Sequence

The layers of pre-glued wood to be formed into the arch are placed between Bands A and B (see Photograph 1, below). (For laminating multiple, identical arches, bands and jaws wider than those shown in Photograph 1 are used.)



Photograph 1: Universal Laminating Device: X and Y Axes and Bands A and B

Both bands must be sufficiently rigid to withstand the tendency to bow out from the pressure when laminating. The bands' rigidity directly affects the curvature desired and the amount of pressure required to laminate effectively.

The bands, with the pre-glued layers between, are then placed through the left and right jaws, as shown in Figure 3-1. In that Figure, the jaws have been offset diagonally along the x-frame. This diagonal offset is used when laminating helical, three-dimensional arches such as the stringers on circular stairs because in that type of arch, the x-frames need to be rotated in unequal amounts.

To form the arch to a desired curvature, both x-frames are rotated: the right x-frame is rotated counter-clockwise, and the left x-frame is rotated clockwise.

The pressure required to laminate the material between Band A and Band B is controlled by the jaws. The pressure between Bands A and B is a function of two factors: (a) the force applied by the rotation of the jaws, with the torquing power of the transmission, and (b) the frictional force which builds up in the material as the jaws are pneumatically pressured up to prevent the bands from slipping.

The arch is thus formed and laminated simultaneously. The layers being laminated and arched are held in the arched position until the glue has set, at which time the arch is then removed from the ULD. Depending on the characteristics of the glue used, this can take 30 minutes or less.

Arches can also be formed with straight sections at either end. Since the jaws on the left and right in Figure 3-1 are 225 mm (10") wide, curved members can have only a 225 mm (10") straight section at either end. To increase the length of the straight sections that could be formed at the ends of the arch, secondary platens can be inserted within the jaws or the jaws themselves can be extended.

Arch Dimensioning

The basic operating principle of the ULD involves the relationship between the surface areas of the material being laminated and the maximum pressure that can be generated between the bands along the length of the workpiece being laminated. The nature of the curve being laminated is not relevant.

Arch shape is determined by first setting the x-axes apart at a distance equal to the interior circumference of the proposed arch. Then the jaws are rotated through the required angle of the arc. This is best explained by the simple arch production illustrated in Figures 3-2 through 3-4.

Figure 3-2 below represents a partial cross-section of the ULD at initial set-up of the material to be formed and laminated.

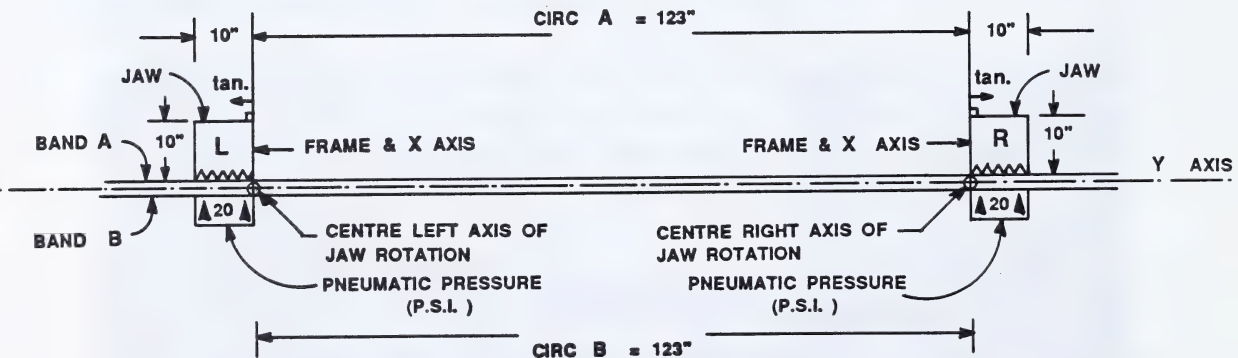


Figure 3-2: Universal Laminating Device "Initial Set-Up"

To begin, a 50 mm (2") layer of thin pre-glued wooden sheets has been placed between Bands A and B. The right x-axis and jaws are fixed, and the left axis has been positioned at a point equal to the proposed interior arch circumference. (In the arch in Figure 3-2, the arch circumference is 3123 mm [123"].)

Once the jaws are positioned, 20 psi of pressure is introduced into each jaw. The right jaw pins Band A at the prescribed circumference and prevents it from moving during the procedure to follow.

In Figure 3-3, the axes have been partially rotated. Band A remains fixed at the circumference (3123 mm [123"]) point. At

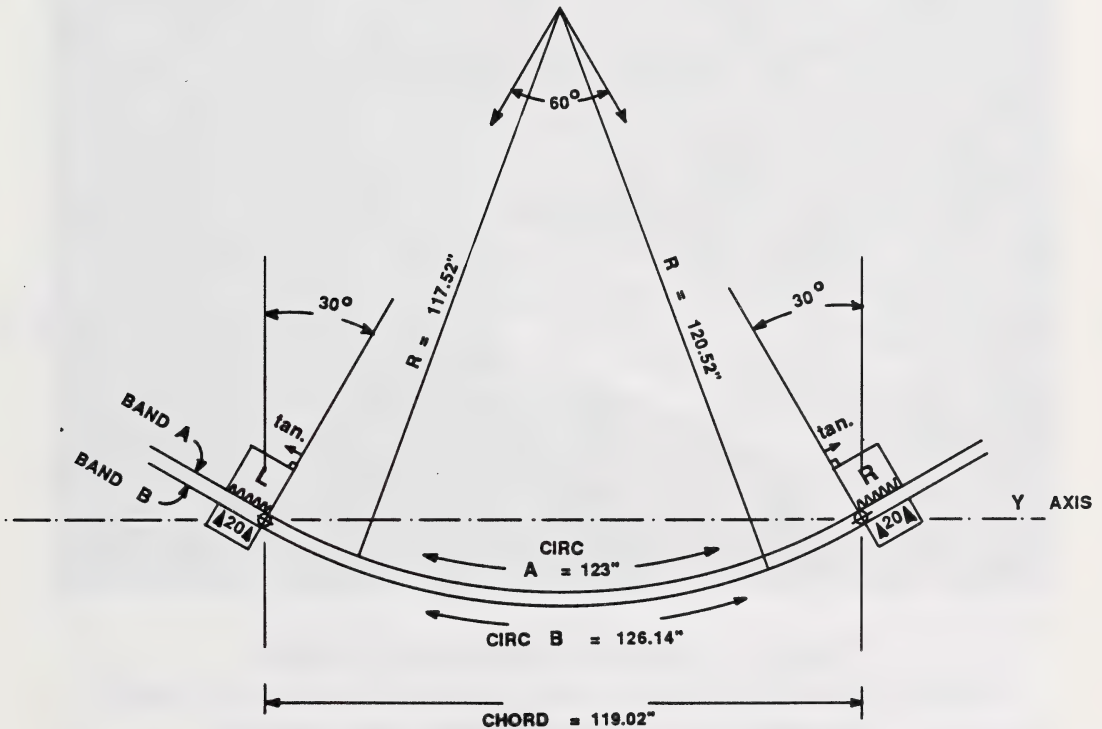


Figure 3-3: Universal Laminating Device "Partial Rotation"

the same time, the relatively low pressure of 20 psi has allowed the left jaw to slide about 75 mm (3") along the y-axis. The distance between the left and right jaws represents the chord measure of the desired arc.

In Figure 3-3, a 60° arc has been formed. At this time, the pressure in both jaws is raised to 70 psi, which stops all further movement of either band.

In Figure 3-4 below, final rotation (90°) has been completed. The circumference at Band A is still constant (3123 mm/123"), but the left jaw has shifted along the y-axis as required to reduce the chord measure and force the laminate to arch into the required specification. The arch is then held in this position for approximately 30 minutes--depending on the glue characteristics--until the glue sets and arch formation has been completed.

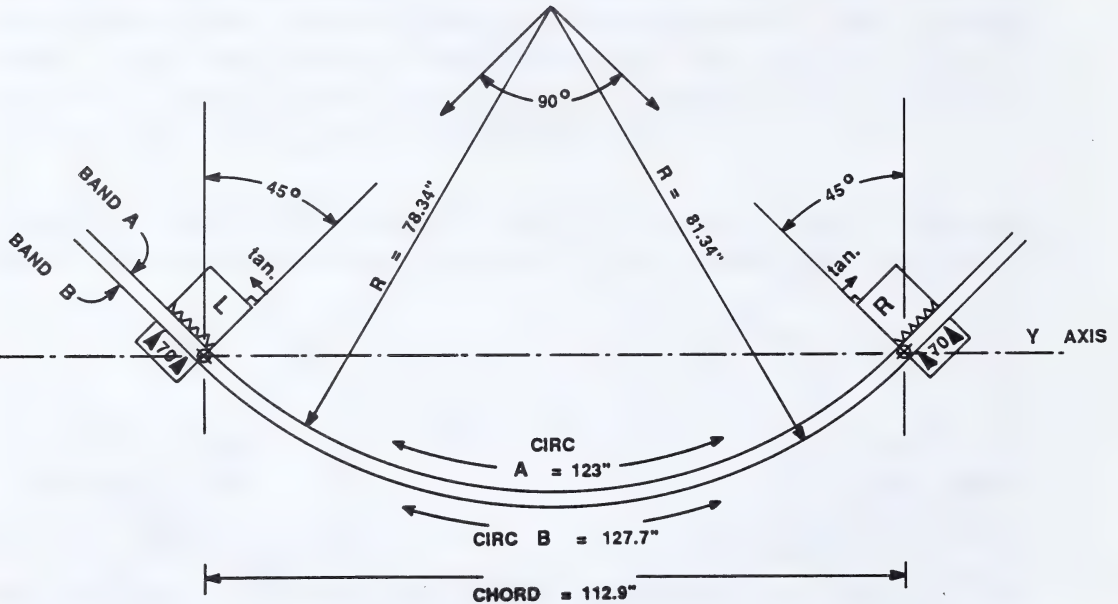


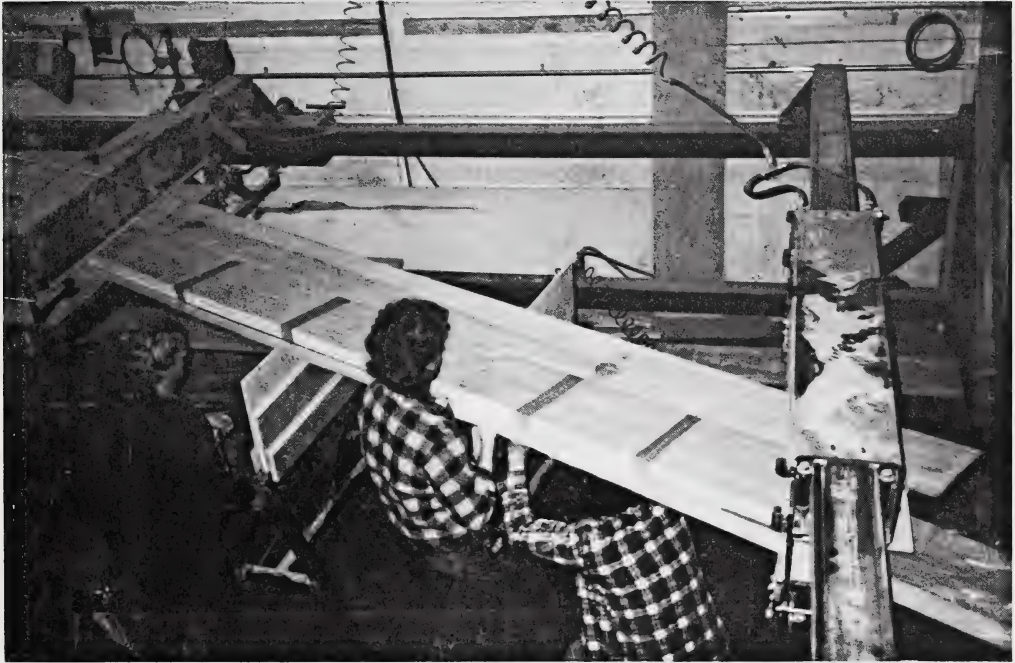
Figure 3-4: Universal Laminating Device "Full Rotation"

3.2.4 Production of Helical Arches on the ULD

The ULD is also capable of manufacturing helical (three-dimensional) curves. Photographs 2 through 7 show the production of a helical stair stringer on the ULD.

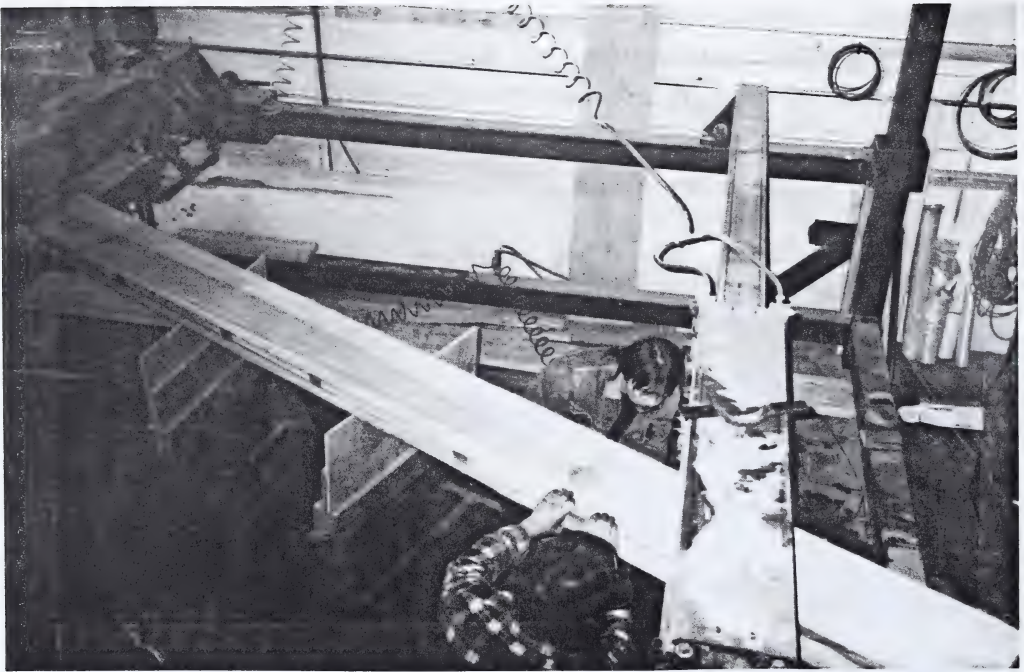
In manufacturing simple arches, Band B must be allowed to slide. While the same principles apply in the manufacture of three-dimensional helical arches, Band B must not only be able to slide but must also be allowed to change slope simultaneously with rotation. To achieve this, one of the jaws must be able to move along the x-axis at the same time that it rotates about that axis.

Photograph 2 shows the wooden layers to be laminated and the preliminary set-up of the slope required for the helical stair stringer. The material layers rest on Band B. Band A has not yet been positioned.



Photograph 2: Universal Laminating Device (Pre-glued material layers on Band B)

In Photograph 3, Band A is now in position over the wooden layers. The bands protrude through both the right and left jaws. These jaws are allowed to slide along the x-axes independently. The right x-axis is in a fixed position, while the left one can slide freely from left to right along a secondary y-axis. The initial x-axis and y-axis settings represent the rise and run, respectively, of the helical stair stringer to be laminated.



Photograph 3: Universal Laminating Device (Band A positioned over material layers)

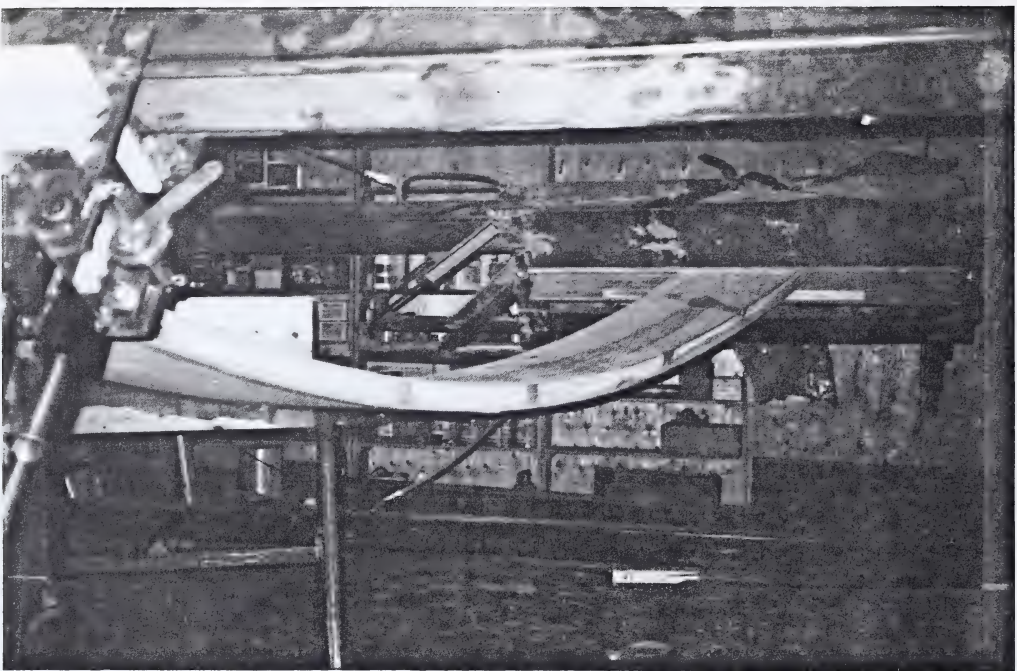


Photograph 4: Universal Laminating Device (Both x-axes have been rotated to form curvature of material layers)

The initial curvature is established by the simultaneous rotation of the two x-frames. At the beginning of the rotation of the two x-frames, Band B is allowed to slide. Photograph 4 shows the helical member at approximately 50° total rotation (25° left; 25° right). At this stage in the procedure, full pressure is injected to both jaws, and Band B is no longer allowed to slide. Photographs 5 and 6 show the rotation procedure completed. To produce this particular arch, the x-axis on the left was rotated 60°, and x-axis on the right 97°.



Photograph 5: Universal Laminating Device on Completion of Rotation Procedure



Photograph 6: Universal Laminating Device View of Helical Arch After Rotation and Pressurization

Photograph 7 is a finished parametric, helical arch, which would form the stringer of a circular stairway.



Photograph 7: A Finished Parametric Helical Arch

3.2.5 Testing and Modifications

All development and testing of the ULD was performed at Exclusive Frame & Arch, Calgary, Alberta. In continuous field tests, the ULD's performance exceeded original expectations.

Tests showed that the entire set-up, formation, and pressurizing procedure for both standard two-dimensional arches and three-dimensional helical arches can be completed in 30 minutes or less, using the existing controls for adjustment and calibration of the x- and y-axes frames and jaws. If the current manual controls were upgraded or computerized, for example, the cycle time per lamination could be reduced by approximately 80 percent.

Modifications to the ULD during the testing phases focused on increasing the versatility (range of possible arch configurations) while increasing the quality and consistency of laminations and curves. This was achieved by increasing the working pressures in the jaws.

In the first ULD prototype, pressure was primarily generated through the clamping action of the jaws. In this initial set-up, there was sufficient pressure between the bands to laminate 300 mm (12") wide arched members. However, the pressure proved to be inadequate when laminations were attempted with 660 mm (26") thick stock, which is the depth of the jaws. It became evident that a method was needed to increase the pneumatic clamping pressure of the jaws or to add more external pressure to increase the working pressures that were required for larger arches. Modifications were made that achieved these increases.

First Modification

Initially, the ULD's transmission for rotating the x-axes frames was located at the centre of the x-axis. It became apparent, however, that in that position, insufficient torque could be created to raise the laminating pressure to the required levels. The torque potential of the transmission needed to be increased to raise the system pressurizing capability. This increase in torque was accomplished by

introducing a cam, which offset the central location of the transmission and created a levered force that increased the torque potential of the transmission by between approximately 6000 in-lbs and 7000 in-lbs.

Second Modification

To improve further the quality of lamination, more pressure was needed, and the focus turned to the pneumatic clamping pressure of the jaws. The jaws needed to be able to accept more pressure. By strengthening the flat-plate platens with a truss-designed back, increased levels of pneumatic pressure could be applied on the jaw platen, thus increasing the friction on the bands. This, in turn, resulted in an increase in the total system pressure.

The additional friction and pressure created necessitated changes to the bands themselves. The bands were initially six layers of laminated wood veneer. These wooden-veneer bands were used for all the original ULD tests, but pressure levels of 30,000 lbs force or more dictated that the bands have a tensile strength that exceeds the material capabilities of the wood. Therefore, the bands were changed to polyethylene sheet plastic as it exhibits several beneficial characteristics:

- impressive tensile strength,
- uniform physical composition,
- stiff, yet flexible, character, with "memory" (that is, after successive curved laminating procedures, the plastic recoils to its original flat sheets)
- a non-stick surface which is ideal for direct contact with the wooden material during laminating and forming, and
- available in 1.2 m x 6.1 m (4' x 20') sheets, which is large enough to accommodate 95% of all products intended for lamination.

Tests are currently being performed with $\frac{1}{2}$ ", $\frac{3}{4}$ ", and 1" thick polyethylene bands.

3.2.6 Summary Analysis of the ULD

Production use confirmed that the ULD overcame the basic limitations of competitive arch-laminating machinery. The ULD's advantages over the competitive machinery are significant. The ULD simultaneously sets up, forms, and pressurizes curved wood elements. Eliminating the need for moulds and extensive set-ups not only saves time and labour costs, but it ensures quality and consistency by reducing the impact of human error. The ULD achieves these results while using only 400 square feet of shop-floor space.

The ULD greatly increases the range of sizes and shapes of curved wood products in both curvilinear and helical formats, with and without straight extensions. Furthermore, due to its potential for simultaneous multiple laminations, it exceeds the overall capacity of current laminating machines. For example, the ULD will laminate material up to 1200 mm wide while the maximum capacity of competitive devices is only 400 mm.

For example, in making helical arches for circular stairways, the ULD combines the versatility of the labour-intensive custom stair shop with the productivity of a massive production shop. Overall, the ULD lowers manufacturing costs by reducing time and labour costs and by minimizing overhead for required floor space. The ULD allows the manufacturer efficiently to produce custom arches at a cost comparable to that of batch production.

3.3 CURVILINEAR MULTI-RIP SAW

The Curvilinear Multi-Rip Saw (CMRS) is a 20 HP multiblade rip saw capable of gang ripping arched stock from the ULD, making up to 10 components of lesser width. These narrower components then form the "rough" stock for secondary profiling procedures. Its primary design innovation is the powered infeed and outfeed attachments, which enable the CMRS to more effectively control the movement of curved stock across the cutting blades.

3.3.1 Description

The Curvilinear Multi-Rip Saw (CMRS), essentially a multiblade table saw, is shown schematically in a rest position in Figure 3-5. It is also shown in greater technical detail in the front and side views of Figures 3-6 and 3-7.

On both the input and output ends, the CMRS has soft rubber powerfeed rollers (3, Figure 3-7). These powerfeed rollers are incised with a spiral groove along their entire length; the groove helps force the stock against the cutting fence, thus enhancing the quality of the cuts.

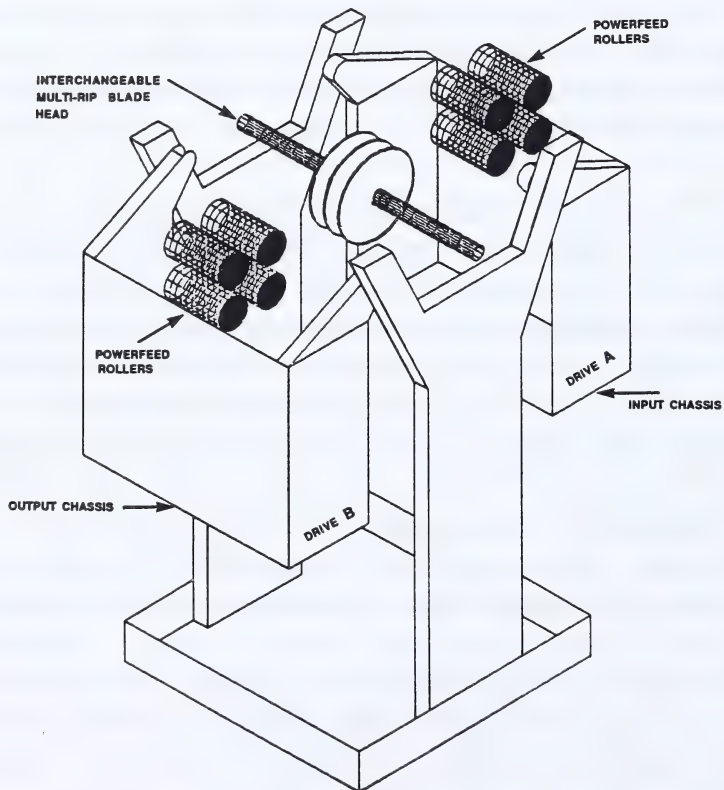


Figure 3-5: Curvilinear Multi-Rip Saw in Rest Position

PARTS DESCRIPTION

- 2 PNEUMATIC CYLINDERS
- 6 HORIZONTAL PLATE
- 8 CAMS
- 10 CENTER OF ROTATION
- 11 PNEUMATIC CYLINDERS
- 12 CENTER OF ROTATION
- 15 RIP BLADES
- A RIGHT PNEUMATIC DRIVE ASSEMBLY
- B LEFT PNEUMATIC DRIVE ASSEMBLY

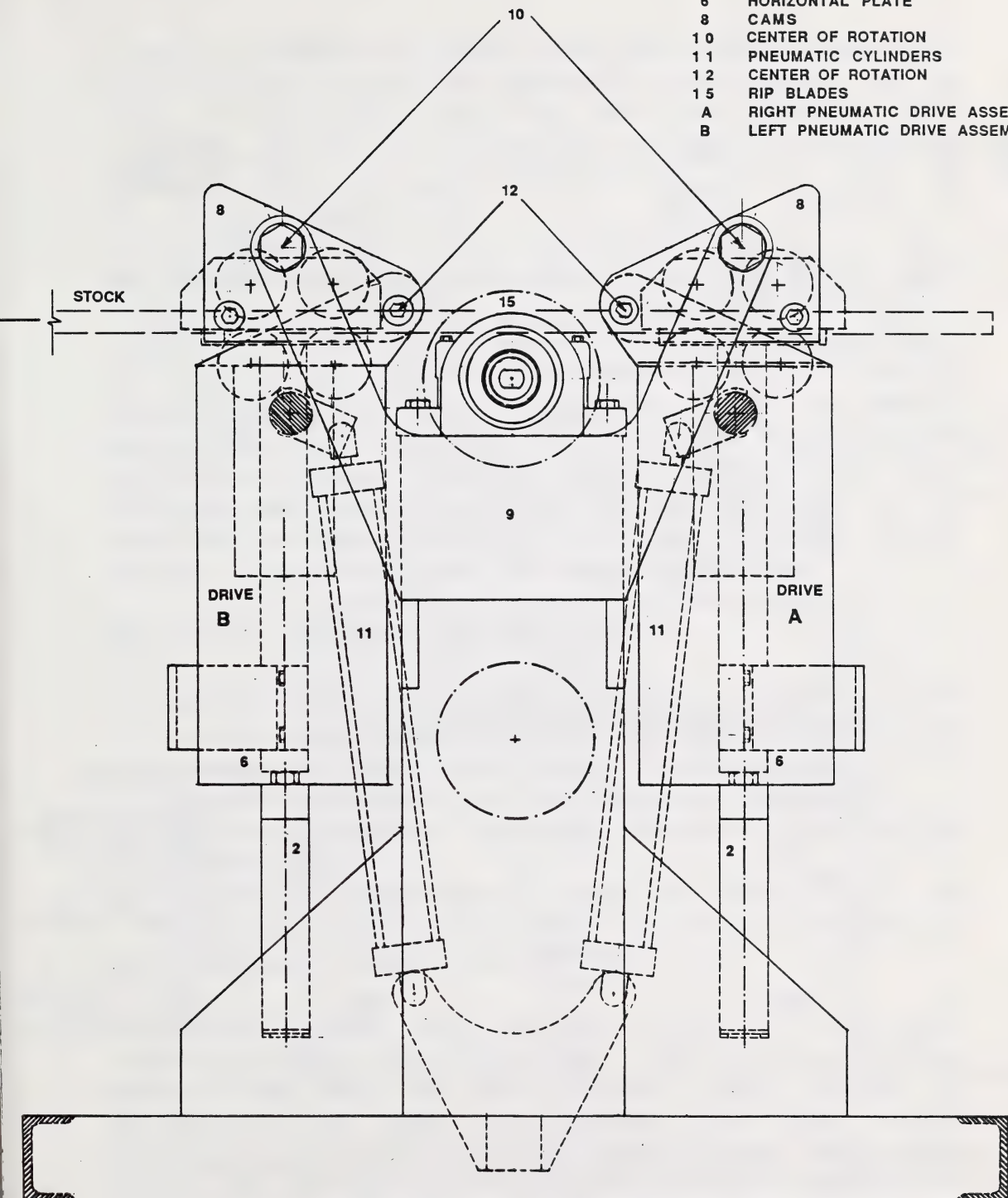


Figure 3-6: Curvilinear Multi-Rip Saw (Front View)

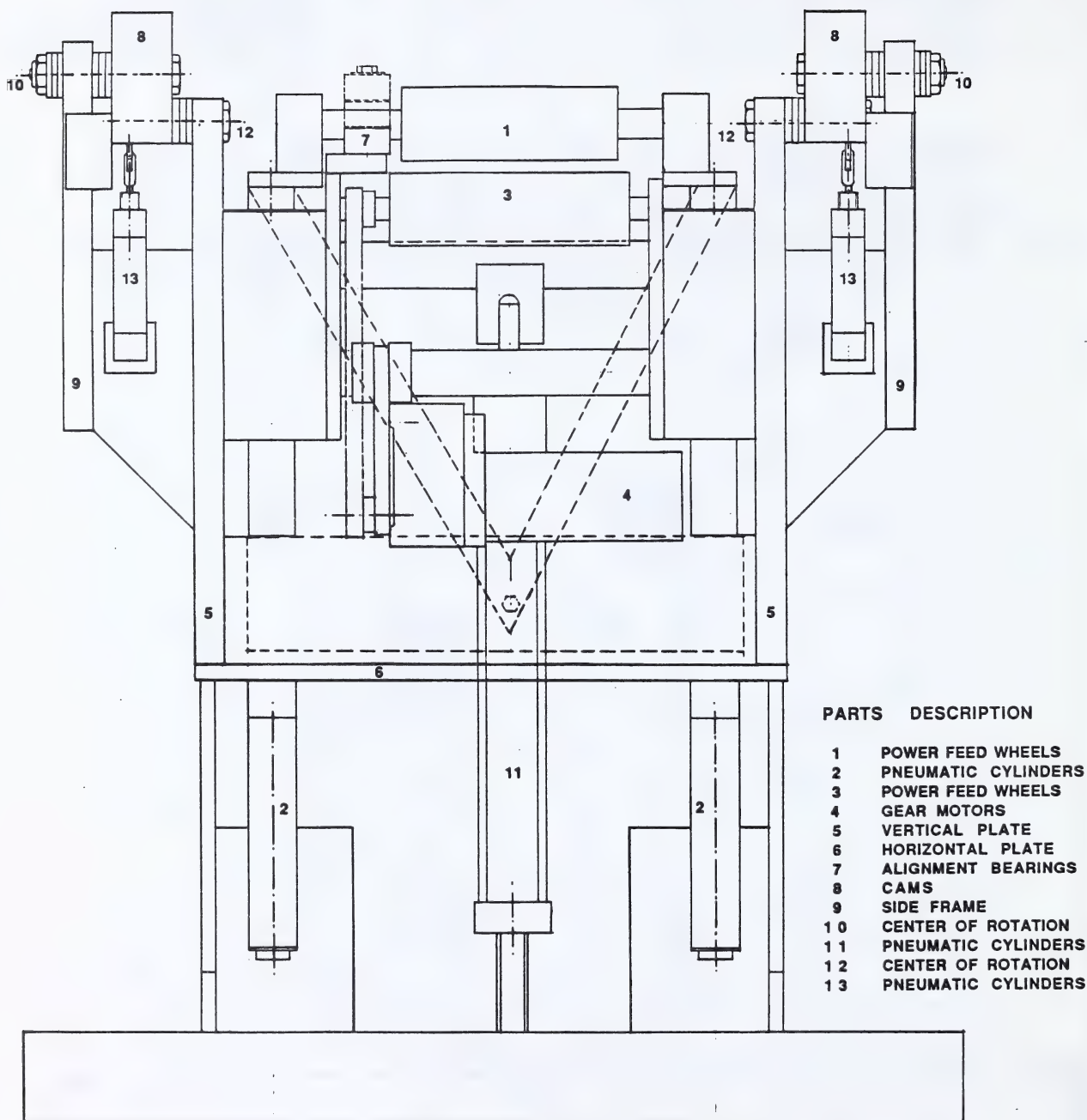


Figure 3-7: Curvilinear Multi-Rip Saw (Side View)

A frame (5, Figure 3-7) forms a yoke that connects these parts as a unit and is called the "pneumatic drive assembly" (A), as shown in Figure 3-6. The right and left pneumatic drive assemblies (A) and (B) are identical and each is independently powered.

3.3.2 Capabilities

The CMRS has been designed to perform about 95% of the arch-cutting procedures currently required in the arch manufacturing industry. The CMRS has been engineered to adapt spontaneously to a wide range of arch configurations, with or without straight extensions, as well as straight stock. The CMRS is capable of ripping any arched stock down to a minimum 150 mm (6") radius and up to a maximum width of 225 mm (10"). There is no minimum height restriction on workpieces that can be ripped by the CMRS. Using up to 10 blades, the CMRS can cut through a maximum of 75 mm (3") thick arched stock.

The CMRS has the following capabilities:

1. adaptable to any length, thickness, height or arch configuration found in typical residential construction;
2. facilitates quick blade changes in response to varying cutting requirements for secondary arch components;
3. minimizes required floor space because of its upright design; and
4. maximizes arch-handling capability because of its powerfeed mechanism, allowing one worker to perform all procedures, which minimizes labour costs.

The interchangeable, multiblade head allows for simultaneous ripping of multiple arch components. With five blades and an average feed rate, the CMRS exhibits a 600% increase in productivity over competitive machines, which have average single-cut rates of 100 mm to 200 mm per second. With eight blades, the CMRS can cut $\frac{3}{4}$ " arched pine stock at a feed-rate of 400 mm (14") per second. With ten blades, the CMRS can cut through a 75 mm (3") solid oak arched member at a feed rate of approximately 75 mm (3") per second.

3.3.3 Basic Principles and Operational Sequence

The CMRS is basically a multiblade table saw to which have been added powered infeed and outfeed attachments. The powered infeed and outfeed allow one operator to easily perform the cutting procedure and to ensure the curved stock maintains constant and consistent contact with the cutting blades. The CMRS is illustrated schematically in Figure 3-5, and Figures 3-8 through 3-10, which have been simplified to better illustrate the basic operation of the CMRS.

The operational sequence of the CMRS is as follows:

a. First, the arched stock is inserted from the right and fed under two soft rubber powerfeed rollers (1, Figures 3-7 and 3-11) that are driven by the variable speed gear motor (4, Figure 3-7). These rollers on the input end grip the arched stock firmly and feed it across the blade head.

When the powerfeed is started, the spiral grooves on the wheels cause the arch stock to 'drift' toward the alignment bearing stacks (7, Figure 3-7). These stacks help ensure arch stability during the ripping procedure.

b. Next, the pneumatic cylinders (2, Figure 3-7) are engaged by a floor-mounted foot pedal control, thus leaving the operator's hands free to guide the arch stock as necessary. The pneumatic cylinders pull the top rollers (1, Figure 3-7) against the inserted arch stock (shown as dotted line), forcing it against the two bottom powerfeed rollers (3, Figure 3-7).

When the curved section of the arch meets the in-feeding rollers (Figure 3-8), the arched stock causes an upward swinging motion of the pneumatic drive assembly (A in Figure 3-6) as that assembly moves to follow the change in the arch shape. This upward swinging motion is necessary to facilitate arch stock ripping and keep the stock in constant contact with the ripping blades. The pneumatic drive assembly, therefore, is permitted to swing in an upward motion via the cams (8, Figure 3-6).

The four-cornered configuration of the powerfeed wheels also helps in the initiation of this upward swing.

Once the arch stock passes the infeed rollers, the swinging motion of the A drive assembly is relaxed, and it returns to a rest position (Figure 3-10).

c. At approximately mid-cycle, the operator moves around the machine to the output end in preparation of removing the multi-ripped arch sections. The stock is then gripped by the output rollers. As the stock is fed out of the device, it is stabilized from sway by the swinging motion of the B drive assembly (shown in Figure 3-9). As the arch stock exits the machine, the B drive assembly also relaxes and returns to a rest position (Figure 3-5).

Because the arch stock remains in a vertical position throughout the cutting operation, its weight is balanced at all times and bears evenly on the cutting head or powerfeed rollers. In addition to the weight of the arch on the cutting heads, the force created by the moveable bearings and the powerfeeds prevents separation of the arch stock.

The views illustrated in Figures 3-5 and 3-6 shows the CMRS in rest position. In this position it would be possible to rip straight stock.

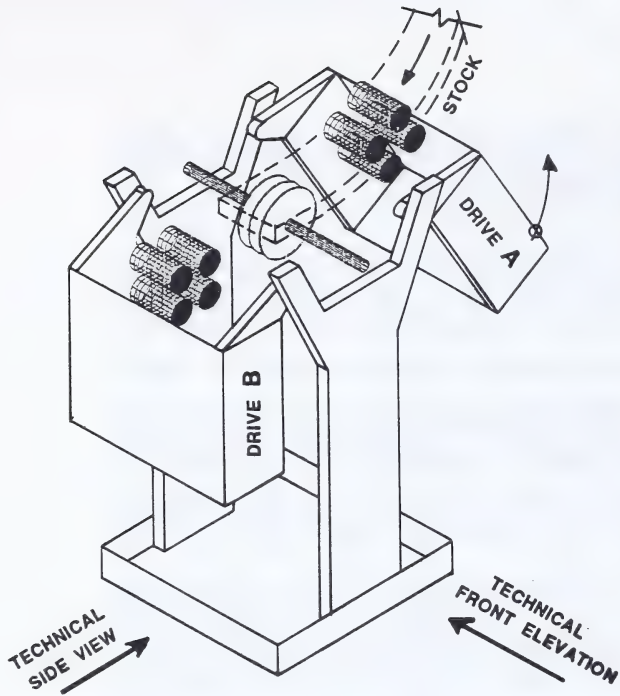


Figure 3-8: Curvilinear Multi-Rip Saw—Relative Position Initiating Rip Procedure

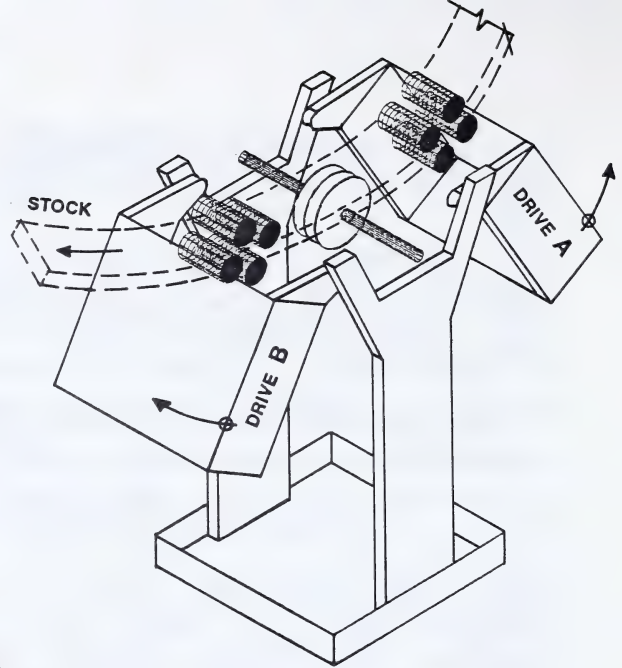


Figure 3-9: Curvilinear Multi-Rip Saw—Relative Position Midway Through Rip Procedure

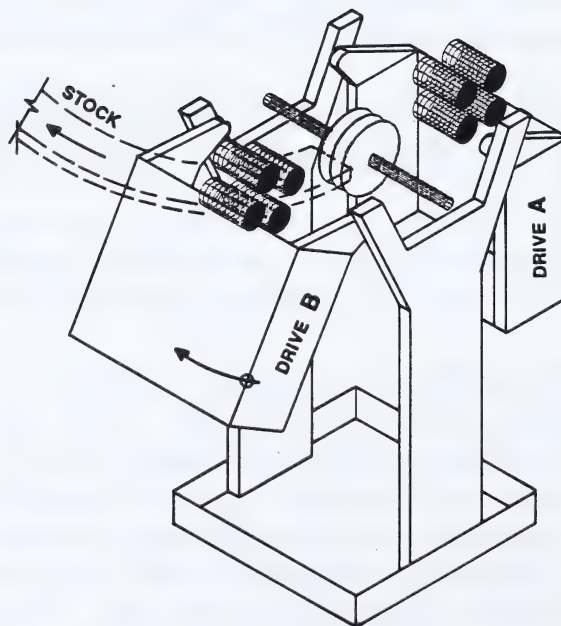


Figure 3-10: Curvilinear Multi-Rip Saw—Relative Position Finishing Rip Procedure

3.3.4 Testing and Modifications

All testing of the CMRS was performed during continuous production use. Modifications were made to increase the cutting speed and the ability to respond to varying arch configurations.

Increasing Cutting Speed

Originally, the CMRS was designed to be driven by a 7 HP motor. To increase the number of blades used and the speed with which stock could be fed through the machine, the CMRS was retrofitted with a 20 HP motor.

Improving Response to Variable Arch Configurations

Keeping the arch stock in constant relationship between the infeed or outfeed rollers and the multiblade ripping head can pose a problem for most milling machines, especially when trying to accommodate arch stock of variable circumference or arches that are curved with straight extensions. This problem was solved in the CMRS by allowing the powerfeed rollers to swing up in response to the stock being fed into the machine. Similarly, the pneumatic cylinders assembly (13, Figure 3-6) is also allowed to swing up to meet varying arch shapes. The cylinders' pneumatic force was increased to supply more downward pulling force on the arch stock when the pneumatic drive assemblies swing in response to the various arch configurations. The angle of cylinders (11, Figure 3-6) was also adjusted to allow for optimum balancing of the stock.

To further ensure that the stock stays in constant relationship to the ripping head, cam range-limiters were installed to limit the upward swinging motion to specific permitted ranges.

Reducing Set-Up Time

Changing the interchangeable multiblade heads requires approximately 13 minutes. If more frequent blade changes were necessary, the entire shaft assembly could be retrofitted to a "quick change" clamp system that could reduce multiblade exchange rate to about 30 seconds or less. However, the CMRS is so versatile that current use dictates only about four blade

changes daily, so retrofitting the "quick change" system is not really cost-effective at this time.

3.3.5 Summary Analysis of CMRS

Innovative design features, such as the unique camming action of the dual powerfeed rollers, permits the CMRS to respond instantaneously to most arch configurations (except "s" turns). In addition, the multiblade configuration increases productivity by 500% to 800% over competing equipment. The CMRS's upright design allows a single operator to perform most arch ripping requirements, even handling heavy and awkward arches with ease. However, when feeding arched stock that exceeds 5.5 m (18') in circumference, a second operator is required briefly to ensure that initial stock alignment is correct.

3.4 VERTICAL ARCH PROFILING DEVICE (VAPD)

Four different components in an average window require profiling (bevelling and contouring). Two of these require vertical arch profiling, for which the Vertical Arch Profiling Device (VAPD) is designed. The term "vertical" refers to the position of the router bit in relation to the powerfeed wheels and to the direction of arch travel during the procedure.

3.4.1 Description

Figures 3-11, 3-12, and 3-13 show the front, side, and top views, respectively, of the VAPD.

The VAPD is a complex router that weighs significantly less than existing competitive machines. The VAPD's simplified arch guidance system reduced its weight. That, in turn, allowed the VAPD to be designed to operate in an upright position, which saves space and increases productivity by allowing a single

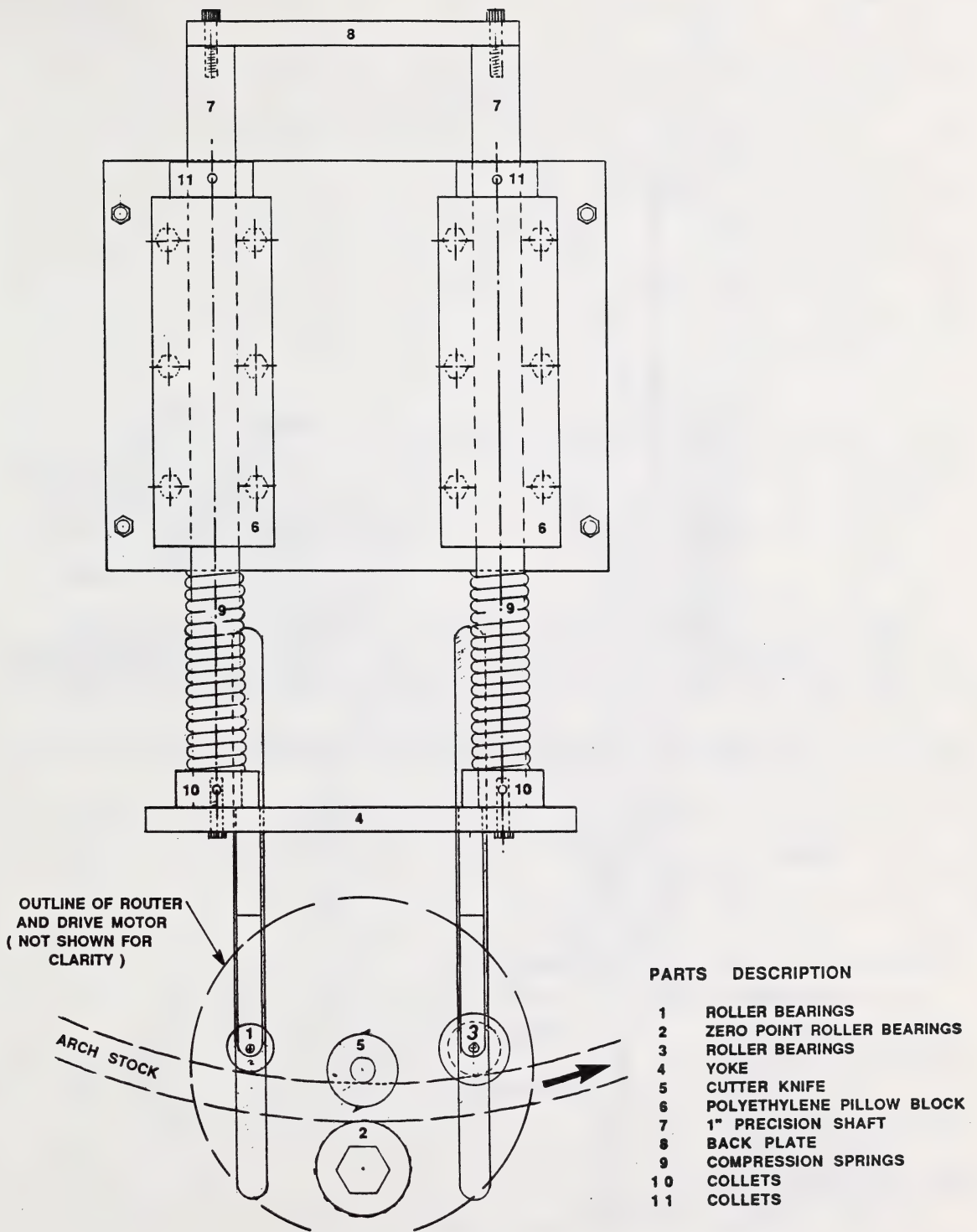


Figure 3-11: Vertical Arch Profiling Device (Front View)

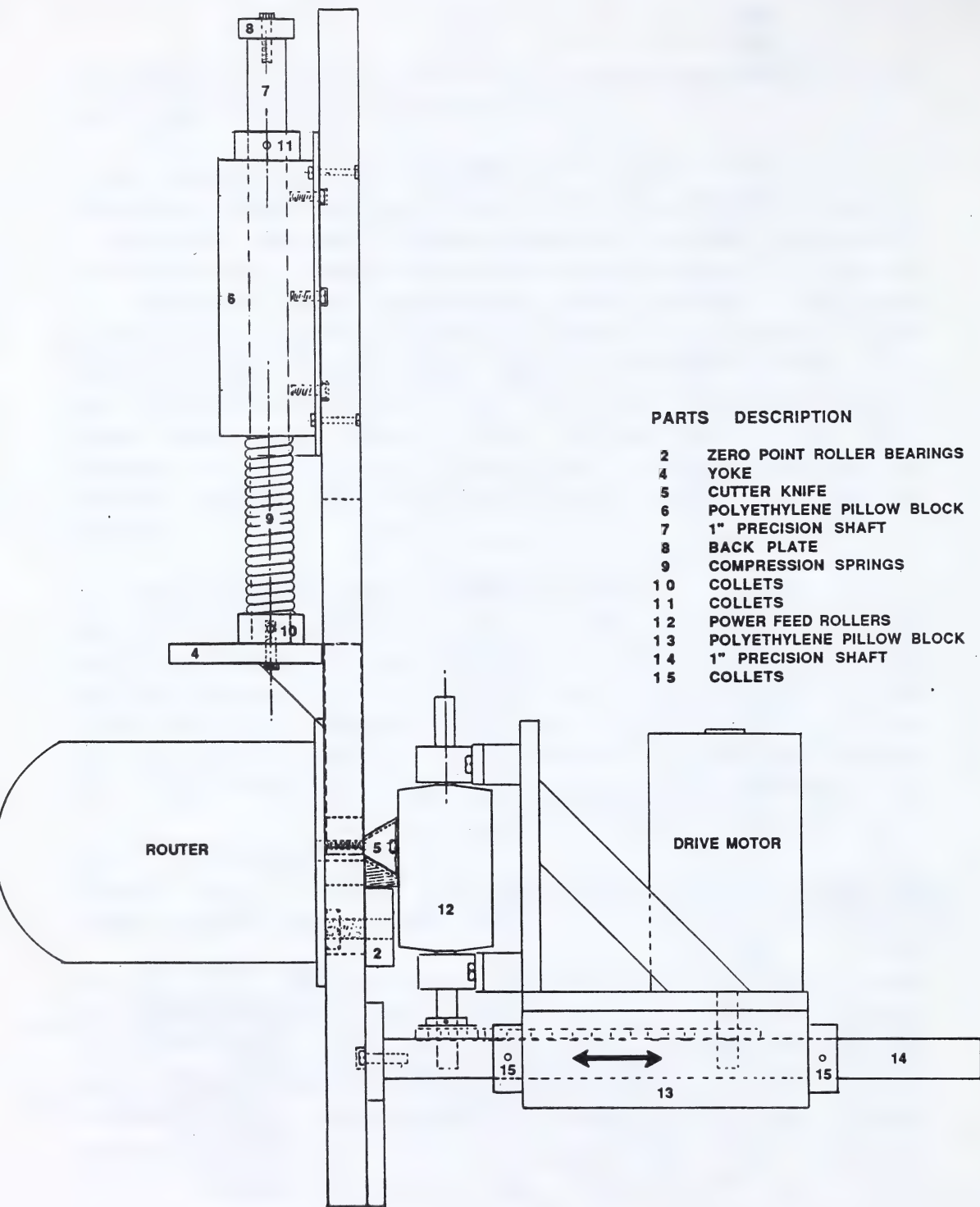


Figure 3-12: Vertical Arch Profiling Device (Side View)

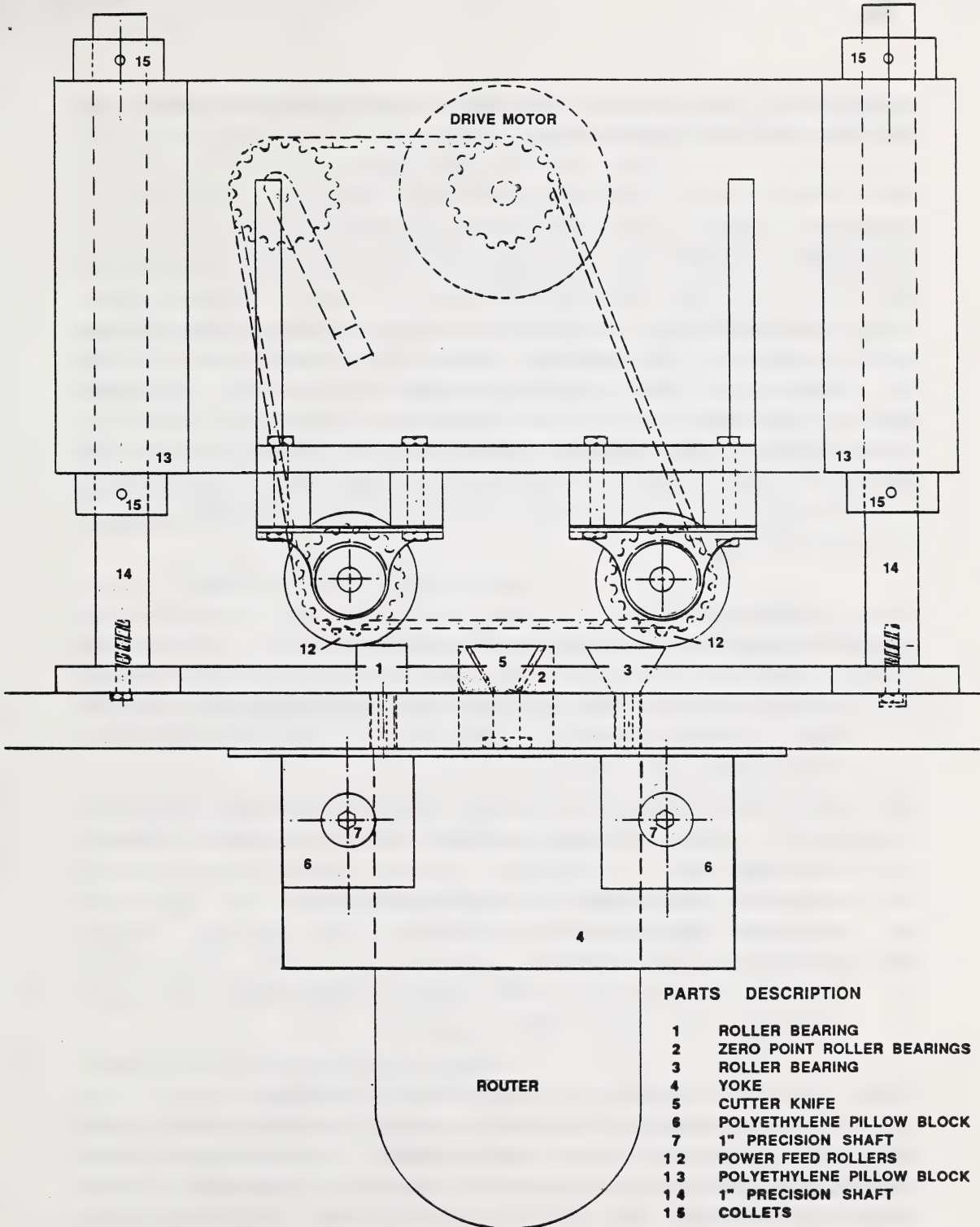


Figure 3-13: Vertical Arch Profiling Device (Top View)

operator to perform vertical profiling efficiently over long periods of time if necessary.

Arch stock is fed into the VAPD through the roller bearings (1, 2 and 3, Figure 3-13) which are arranged in a stabilizing triangular format, to help guide the stock. The stock is stabilized and gripped by bearings (1 and 3, Figure 3-13), which are moveable and are connected by a spring-loaded twin-axis assembly. This assembly uses polyethylene pillow blocks (6, Figure 3-13) whose movement along the 25 mm (1") precision shafts (7, Figure 3-13) is controlled by the collets (11, Figure 3-11). This guidance system allows the VAPD to respond easily to arch stock of varying size and shape, keeping the arch stock in optimal contact with the interchangeable cutters (5, Figure 3-13).

3.4.2 Capabilities

The VAPD has the following capabilities:

1. accepts a wide range of stock heights and widths: arches with a minimum radius of 150 mm (6"), straight sections, and reverse 's' curves;
2. self-adjusts for diverse arch radii, elliptical, circular, curved, and straight material and their various combinations;
3. accepts a wide range of cutting knives;
4. increases efficiency of profiling;
5. reduces capital costs;
6. reduces or eliminates most set-up costs; and
7. minimizes the floor space required.

3.4.3 Basic Principles and Operational Sequence

The Vertical Arch Profiling Device (VAPD) profiles the ripped arch stock from the CMRS. For example, a 200 mm (8") wide arched member could be formed and laminated on the ULD and then ripped into 25 mm (1") sections in the CMRS. These sections are then vertically profiled (bevelled, contoured, etc.) on the VAPD according to architectural specifications into components ready for assembly.

The operator introduces the arch stock into the VAPD's powerfeed system, which consists of two powerfeed rollers (12 in Figure 3-11) on either side of the router.

As shown in Figures 3-11 and 3-13, the arch is further balanced and guided through the VAPD by the stabilizing triangular arrangement of the roller bearings (1, 2, and 3). Although, the zero-point bearing (2) is fixed, the other two bearings (1 and 3) are moveable. Connected by a spring-loaded twin-axis assembly, with polyethylene pillow blocks (6), bearings (1 and 3) move and adjust in response to the size and shape of the inserted arch stock. The bearings and twin-axis assembly serve to force the stock against the interchangeable cutters (5) for a consistent cut.

3.4.4 Testing and Modifications

The Vertical Arch Profiling Device (VAPD) has proven to be dependable, efficient and versatile. In ongoing production testing, the VAPD has achieved vertical profiling results with an accuracy tolerance as consistent as machines costing eight times as much.

The VAPD is prototype #3 of a series of profiling devices that have already been tested and implemented as part of Exclusive Frame & Arch Ltd.'s ongoing operations. The objective with prototype #3 was to simplify its mechanical design and to reduce capital costs without sacrificing efficiency or versatility, while maintaining the quality of the profiled components produced on it.

Improving Profiling Efficiency

For initial testing, two cutters were used on the VAPD, producing a smooth component finish at a feed-rate of about 75 mm (3") per second. The feed-rate was increased by about 33% when an additional cutter was added. When three cutters were used, they increased the feed-rate to about 115 mm (4½") per second.

Increasing Productivity

It was discovered that because of the VAPD's low cost and space efficiency, two of them could be arranged as a "bank" (Figure 3-14). This reduces or eliminates set-up costs: each VAPD can be set up to perform particular and different profiling tasks as part of overall arch production.

To increase versatility and efficiency even more, an upright bank consisting of two VAPDs and two Horizontal Arch Profiling Devices (HAPDs)--described in Section 3.5--could handle all vertical and horizontal profiling needs. More important, two VAPDs and two HAPDs would cost only 40% of the capital cost of the comparable existing profiling equipment. In addition, and perhaps almost as important, this bank arrangement would require 50% less floor space than competitive machines.

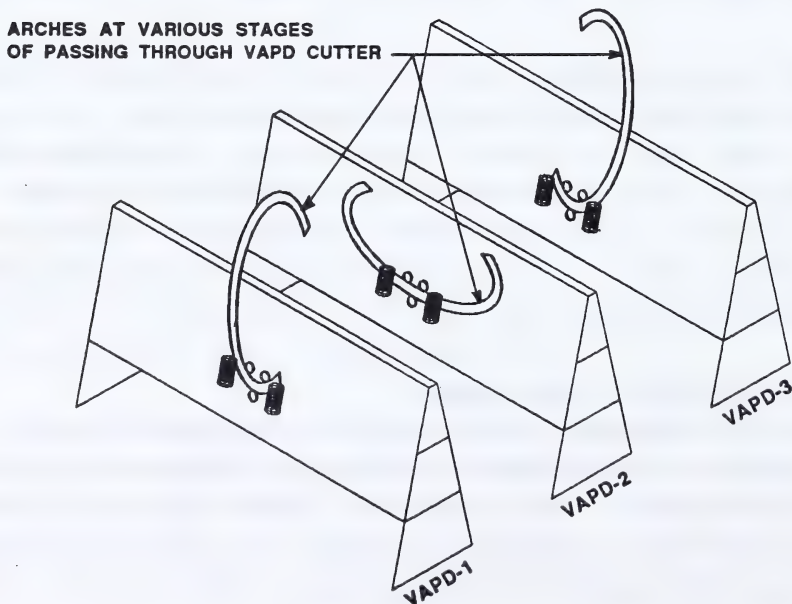


Figure 3-14: Several VAPDs Arranged as Upright "Bank"

3.4.5 Summary Analysis of VAPD

Existing vertical profiling technology is not only a costly investment but also very space-consuming. The VAPD overcomes both those limitations. The estimated capital cost of the VAPD is approximately 80% less, at approximately \$2000, than the cost of similar current machines.

Furthermore, productivity can exceed that of existing machines by about 200% if two VAPDs were installed facing each other so the operator could use both simultaneously.

In summary, the VAPD represents a significant improvement in flexibility, ease of operation, and cost-effectiveness over the machines currently in the marketplace.

3.5 HORIZONTAL ARCH PROFILING DEVICE (HAPD)

The Horizontal Arch Profiling Device (HAPD) is required for profiling such items as the brick moulds on arched windows. This profiling device is similar to the VAPD except that its cutting blades approach the arch stock horizontally.

The primary advantage of the HAPD is evident when profiling heavier arches. It eliminates the need for two workers to handle the arch stock as is the case with existing horizontal profiling machines.

3.5.1 Description

The HAPD profiles the ripped arch stock from the CMRS, just as the VAPD does--except the HAPD cuts from a horizontal plane. The router bit approaches the arched stock from the horizontal plane in relation to the powerfeed wheels and the direction of arch travel during the procedure.

The HAPD can also be aligned upright, similar to the VAPDs shown in Figure 3-14, and this not only simplifies arch-handling but also saves shop floor space.

3.5.2 Capabilities

The HAPD has the following capabilities:

1. accepts a wide range of stock heights and widths: arches with a minimum radius of 150 mm (6"), straight sections, and reverse 'S' curves;
2. self-adjusts for diverse arch radii, elliptical, circular, curved, and straight material and their various combinations;
3. accepts a wide range of cutters;
4. increases efficiency of profiling;
5. reduces capital costs;
6. reduces or eliminates most set-up costs; and
7. minimizes the floor space required.

3.5.3 Basic Principles and Operational Sequence

The upright alignment and the arch guidance system of the HAPD is similar to that of the VAPD and results in easy handling by one operator, which saves both time and labour costs. The consistent accuracy of the profiling is equal to the most stringent industry requirements.

The basic principles and method of operation of the HAPD are virtually identical to those of the VAPD (see Section 3.4).

3.5.4 Testing and Modifications

As with the VAPD, the HAPD was tested during continuous production use, and it proved to be as consistently reliable as the VAPD.

Being developed after the VAPD, this device incorporated most of the design changes that resulted from earlier testing of the VAPD. Therefore, the HAPD was fabricated as an upright router, incorporating the lighter, more effective guidance system derived from the VAPD.

Any modifications that might be made to the HAPD to increase its efficiency would be similar to those made to VAPD, such as increasing the number of cutters to improve the cutting speed.

Currently, however, upgrading the HAPD is not a cost-effective priority at this time. The major reason for this is that the VAPD is so effective in itself that it can do most of the necessary routine profiling. Thus, the HAPD is usually reserved for profiling of very heavy or awkward arches.

3.5.5 Summary Analysis of HAPD

During production testing, the HAPD horizontally profiled arches consistently to industry-standard tolerances. The estimated capital cost of the HAPD is more than 60% less than the capital cost of the comparable competitors in the current marketplace. Furthermore, the HAPD's upright positioning reduces labour costs by allowing one operator to perform horizontal profiling of arches (whereas competitive existing machines require two workers). Finally, the HAPD's upright design also reduces the valuable shop space needed by more than half.

4.0 COMPARISON OF PROJECT MACHINES TO COMPETITORS

The arch-making and milling machines currently available have many limitations that inhibit manufacturers from increasing quality and versatility while increasing efficiency and keeping costs down. When a few comparisons are made, the improvement over the existing machines by those developed during this project becomes obvious.

4.1 TIME AND LABOUR COSTS

Most existing machines require long manufacturing-cycle times and extensive labour to create laminated arches. Except for the highest-priced arch-making equipment, all existing arch-making machines depend on the manufacture of a core-mould, which lengthens the laminating cycle by as much as five times. The ULD, in contrast, simultaneously sets up, forms, and pressurizes curved wood elements, eliminating the need for moulds and extensive set-ups.

For arch ripping, the existing machinery is less efficient than the CMRS because the set-up time is longer than the time it takes to do the actual cutting. By contrast, the CMRS, with its multiblade configuration, can rip stock five to eight times faster than existing milling equipment.

To profile laminated arches, the machines developed in this project also have major advantages over the existing machinery. The VAPD is 80% less expensive than comparable machinery currently on the market. The VAPD also attains a 33% greater cutting rate.

The capital cost of the HAPD is estimated to be about 60% less than the capital cost of comparable horizontal profiling machines. Furthermore, existing profiling machines require two workers to operate them for horizontal arch profiling, whereas the HAPD can be operated by one worker.

4.2 SPACE REQUIREMENTS

Another advantage shown by the machines developed during this project is that they are space-saving. For example, the ULD can fabricate circular staircases of almost any size or shape. Comparable results from existing adjustable cage machinery would require an average of 25 cages. That many cages would consume anywhere from 5000 to 15,000 square feet. The ULD, on the other hand, needs a mere 400 square feet, which provides a considerable saving in overhead.

The VAPD and HAPD, because of their upright design, take up only one-half the space of currently available horizontal and vertical profiling machines.

4.3 VERSATILITY

The ULD greatly increases the range of sizes and shapes of curved wood products in both curvilinear and helical formats, with and without straight extensions. Two of the existing arch-manufacturing machines are not capable of creating arches with straight extensions, for example.

Furthermore, due to its potential for simultaneous multiple laminations, the ULD exceeds the total capacity of current laminating machines. For example, the ULD will laminate arches up to 1200 mm high while the maximum capacity of competitive devices is only 400 mm.

Lastly, none of the existing arch-making machines that make simple two-dimensional arches can make three-dimensional helical arches as the ULD can. The only existing machine for helical arches costs about \$35,000 (US). And even with its helical arch-making capabilities, a stair cage is not as versatile as the ULD because it requires dismantling and reassembly for each new stair constructed.

4.4 CONSISTENT QUALITY

While there is no question that the engineering and reliability of the existing machines are industry-standard, the quality of arches is not as great as those produced on the ULD.

Because three out of four of the currently available arch-making machines rely on pre-manufactured moulds, the accuracy of the size and shape of the arch is dependent on the accuracy of the mould. The possibility of human error affecting the manufacture of the mould is always present, unlike the ULD's process where accuracy is built-in. Even a stair cage is susceptible to human error. And lack of accuracy in the size and shape of the arch will not only pose problems when it fails to meet architectural specifications; it may also have a detrimental effect on the aesthetic appeal of the arch.

The second area where quality might be affected is in the lamination itself. Quality lamination requires both high pressure and equal pressure over the whole surface of the arch being laminated. The ULD provides both, but some of the existing machines have built-in pressure limitations to avoid mechanical breakdown. The result of those limitations is that there are points on the arch where less pressure is applied and the lamination will be weakened at those points. Delamination could thus occur.

5.0 CONCLUSIONS

In general, the following conclusions can be drawn from this project:

1. The machines currently available to arch manufacturers have many limitations and deficiencies, and therefore, these machines are not conducive to cost-effectiveness, versatility, or quality manufacturing.
2. The machines developed and tested during this project--the Universal Laminating Device (ULD), the Curvilinear Multi-Rip Saw (CMRS), the Vertical Arch Profiling Device (VAPD), and the Horizontal Arch Profiling Device (HAPD)--all overcome the limitations found in the currently available machinery.
3. The machines developed and tested in this project achieved the goals of:
 - (a) increased cost-effectiveness by minimizing needed manufacturing space and reducing overhead and by reducing labour costs and increasing productivity;
 - (b) increased versatility and improved customer-service and market-responsiveness through reduced batch size, even one-of-a-kind production; and
 - (c) improved quality through reduced human error.
4. The estimated capital costs of the ULD, CMRS, VAPD, and HAPD are significantly less than existing arch-making and profiling equipment.
5. The machines and their manufacturing process can effectively meet needs of Alberta's new and retrofit construction industry, where curved wood elements and finishings are increasingly being demanded by homeowners.

On February 25, 1992, Exclusive Frame & Arch Ltd. entered a Joint Research Venture with the Alberta Research Council to commercialize and expand upon the ULD's unique laminating technology. Phase I of the Venture seeks to achieve 80% automation of the complete manufacturing cycle from raw material to final, market-ready assembly of curvilinear arched products. Phase II will continue to expand the product range and further develop the specialized technology.

At the current rate of development, it is expected the ULD family of machines and related production processes will soon represent the favoured, if not the normal, worldwide method of producing curved wood products.

